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EXPERIMENTAL BASIS OF SEVERAL METHODS OF PREVENTING UNFAVORABLE EFFECTS OF WEIGHTLESSNESS

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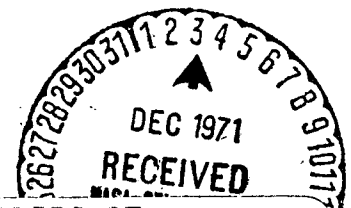

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EXPERIMENTAL BASIS OF SEVERAL METHODS OF PREVENTING UNFAVORABLE EFFECTS OF WEIGHTLESSNESS

A. M. Genin and I. D. Pestov

ABSTRACT: The authors present the results of experiments dealing with the suitability of laboratory simulation of weightlessness in order to test various preventive measures against the unfavorable influences of prolonged weightlessness on the human organism. They conclude that laboratory simulation, although not the final solution, is a step in the right direction.

A decade of experience with manned spaceflights has provided considerable /1* material for an objective evaluation of the limitations posed by weightlessness and the duration of space missions. Nevertheless, discussions are still going on today regarding the necessity for producing artificial gravitation aboard spacecraft, whose length of flight exceeds 2-3 months. The technical difficulties involved in producing artificial gravitation are generally known, so that it is appropriate to consider other methods which could lengthen the time of possible stay of man in space. The unpleasant consequences of the influence of weightlessness showed up clearly on the 18-day flight of A. G. Nikolayev and V. I. Sevast'yanov aboard the "Soyuz-9", regarding which more details will be provided in the first paper.

It should be pointed out that the reactions which the cosmonauts displayed upon returning to terrestrial gravitation were largely similar to those which developed when using simulation in experiments involving immersion in water and clinostatic hypodynamia.

*Numbers in the margin indicate pagination in the foreign text.

This fact supports the theoretical basis of the suitability of laboratory simulation of weightlessness and in any case justifies the testing of various preventive measures in simulative experiments.

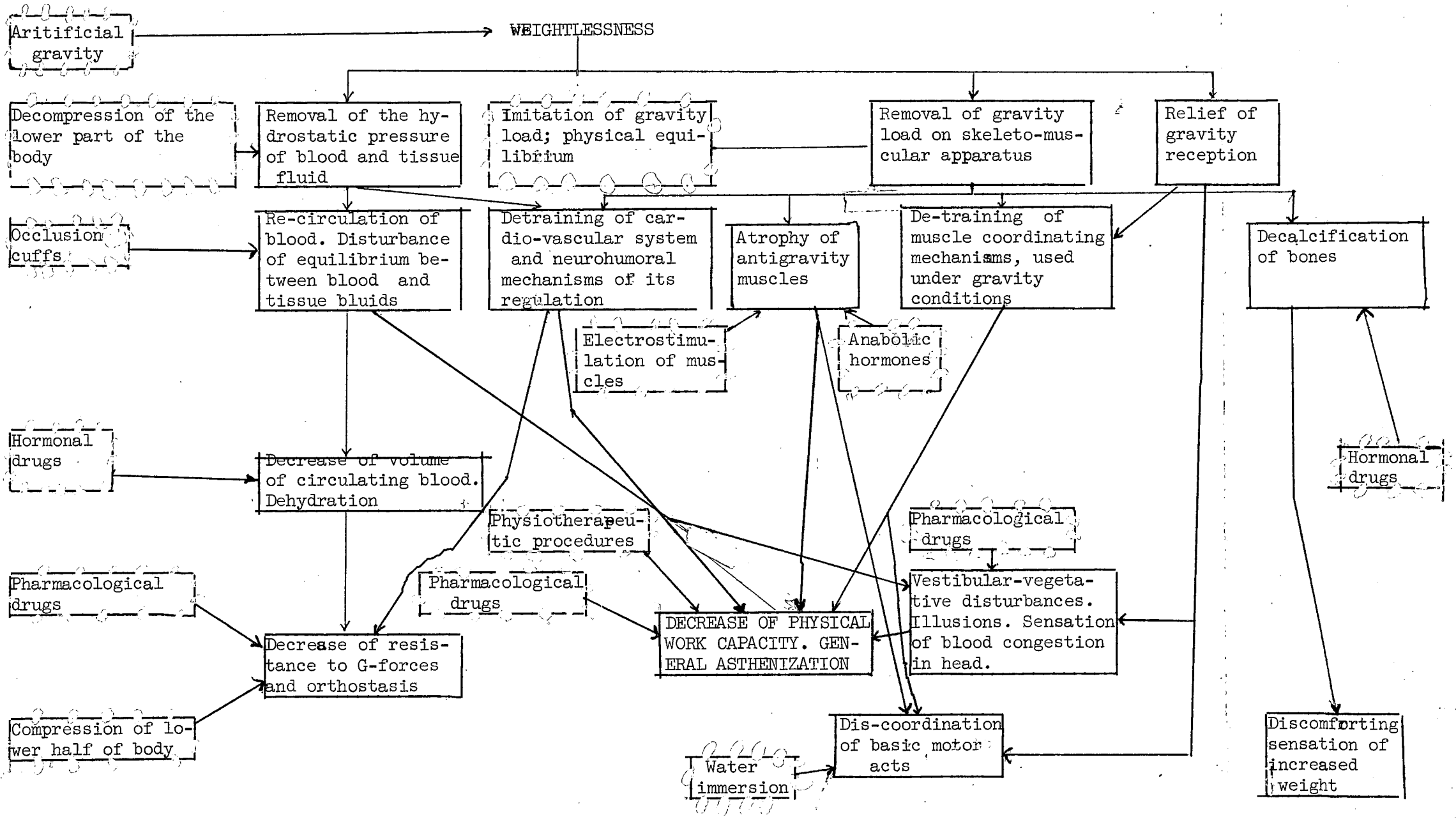
At the present time, a great many methods and means of preventing unfavorable effects of weightlessness have been proposed [Korobkov, 1963; Mueller, 1963; Lazul (?) Stevens, 1965; Miller et al., 1965; Stevens et al., 1965, 1966; McCally et al., 1966, 1968; Katkovskiy, 1967; Vogt, Johnson, 1967; Cherepakhin, 1968; Yeremin et al., 1969; Genin et al., 1969]. /2

The pathogenetic approach to the selection of these methods is characteristic (Figure 1).

The figure shows a schematic representation (simplified to a large extent) of the pathogenesis of the development of disturbances caused by weightlessness and manifesting themselves both on the flight itself and in the period following. The rectangles bounded by red* frame show the various preventive measures that are designed to counter a given unpleasant effect and therefore all of the chains following it. In selecting the measures for experimental approbation, we proceeded on the basis of the assumption that the most effective, natural and practically meaningful methods were those which were based on offsetting those initial effects of weightlessness such as a decrease in the hydrostatic pressure of the blood and removal of gravitational stress on the bone and muscle apparatus. Practically speaking, the selection of a method of combatting the sensory effect of weightlessness is more complicated, although its significance in the pathogenesis of the development of various disturbances is apparently quite important.

The daily discomforts associated with weightlessness are not immaterial for man, but we will not deal with this problem in the present report. (Figure 2).

*Translators' Note: the Red lines are not distinguishable in the foreign text; however the rectangles believed to be so bounded are depicted with a broken-line perimeter.


Aritificial gravity
WEIGHTLESSNESS
Decompression of the lower part of the body
Removal of the hydrostatic pressure of blood and tissue fluid
Imitation of gravity load; physical equilibrium
Removal of gravity load on skeleto-muscular apparatus
Relief of gravity reception
Occlusion cuffs
Re-circulation of blood. Disturbance of equilibrium between blood and tissue bluids
Detraining of cardio-vascular system and neurohumoral mechanisms of its regulation
Atrophy of antigravity muscles
De-training of muscle coordinating mechanisms, used under gravity conditions
Decalcification of bones
Electrostimulation of muscles
Anabolic hormones
Hormonal drugs
Decrease of volume of circulating blood. Dehydration
Hormonal drugs
Physiotherapeutic procedures
Pharmacological drugs
Pharmacological drugs
Pharmacological drugs
Vestibular-vegetative disturbances. Illusions. Sensation of blood congestion in head.
DECREASE OF PHYSICAL WORK CAPACITY. GENERAL ASTHENIZATION
Decrease of resistance to G-forces and orthostasis
Compression of lower half of body
Dis-coordination of basic motor acts
Water immersion
Discomforting sensation of increased weight
LANDING

Figures 1

a b

Figure 2

NOT REPRODUCIBLE

Among the methods designed to combat the effect of reduced hydrostatic pressure of the blood, we shall discuss the use of decompression of the lower part of the body with the aid of vacuum chambers of various designs and the respiration under excess pressure, used to imitate hydrostatic pressure. The preventive effect exerted on the intermediate branches of this pathogenetic chain is accomplished with the aid of occlusion sleeves and the final effect (reduction of orthostatic resistance) is prevented with the aid of compression of the lower half of the body and the use of pharmacological stimulants (Figures 3 and 4).*

*Translator's Note: Figures 3 and 4 were not available.

MEAN DATA OF TENSILITY (ml/100 cm^3 tissue) AND CONTRACTILITY (%) OF LOWER EXTREMITIES VESSELS IN OCCLUSIVE PLETHYSMOMETRIC TESTS

CONDITION OF RECORDING	WITHOUT OCCLUSIVE TRAINING (10 SUBJ.)		WITH OCCLUSSIVE TRAINING (6SUBJ.)	
	TENSILITY $\bar{x}\pm m$	CONTRACTILITY %	TENSILITY $\bar{x}\pm m$	CONTRACTILITY %
BEFORE BED REST	1,36±0,057	104	1,25±0,027	92
THE 40-th DAY OF BED REST	0,95±0,067	74	1,19±0,107	88
THE 60-th DAY OF BED REST	0,95±0,079	85	1,19±0,102	104
IN A MONTH AFTER BED REST	1,36±0,17	101	1,37±0,097	104

Figure 5 (?)

Prevention of the principal consequences of removing the weight stress on the bones and the supporting apparatus is accomplished by developing constant and varying stresses which imitate gravitational effects.

We consider it important to devise methods and means which will allow the cosmonauts to carry out movements which are similar in their biomechanical structure to walking, running, and lifting weights while he is in a state of weightlessness.

The following general plan was selected for experimental testing. The initial selection of the majority of preventive measures and the determination of the rules for their utilization was performed in comparatively short (18 hours) experiments with water immersion, with the final evaluation and refinement of the schedules being conducted in long (30-100 days) experiments with a clinostatic state of hypodynamia. (Figure 5)

In these experiments, effects were studied that were produced by the following methods:

1. Use of occlusion thigh sleeves with a pressure of 65 mm Hg per minute and pauses of 1 and 3 minutes for 7 hours out of an 18-hour period of experimentation.

2. Lowering the level of the compensating counterpressure of the immersion medium on the lower half of the body to a value of 25 mm Hg (during the entire 18-hour duration of the experiment). (Figure 6)

3. Periodic increase of intrathoracic pressure by respiration with a resistance on the exhaust for 2.5 hours of immersion. Level of resistance--200 mm water column.

4. Breathing under excess pressure for 3 hours of immersion. Level of excess pressure--300 mm water column.

5. Use of a group of pharmacological stimulants (caffein, tea, strychnine, phenamine) one hour prior to the end of the experiment and performance of an orthostatic test. (Figure 7)*

*Translator's Note: Figure 7 was not available.

6. Use of an antioverload suit following the end of the experiment, and during performance of the orthostatic test (the following pressure levels were tested in the G-suit chambers: 20, 35 and 50 mm Hg).

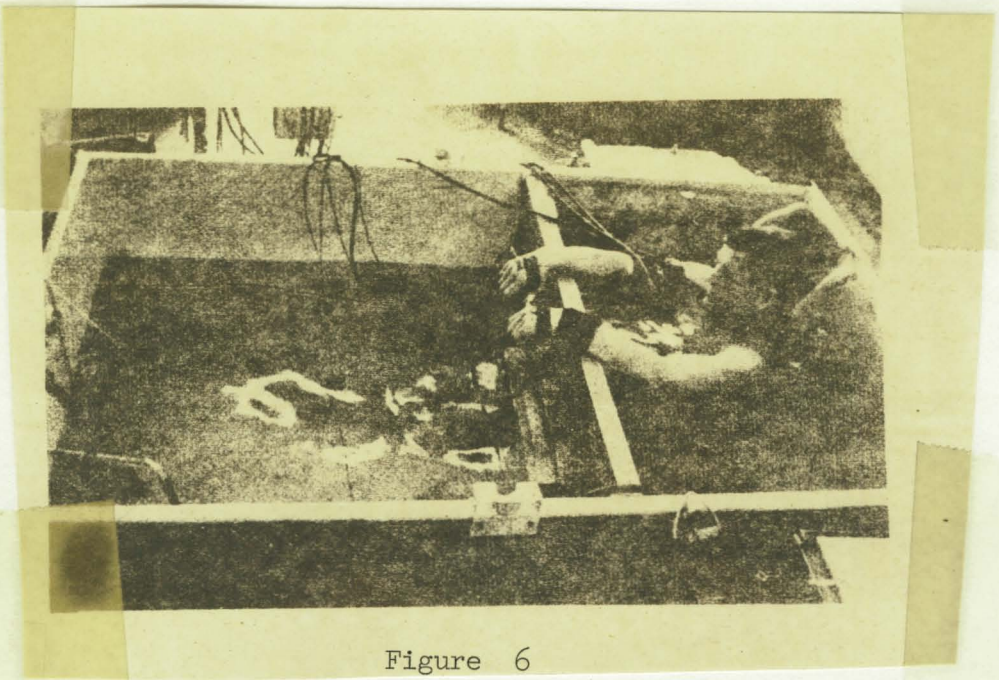
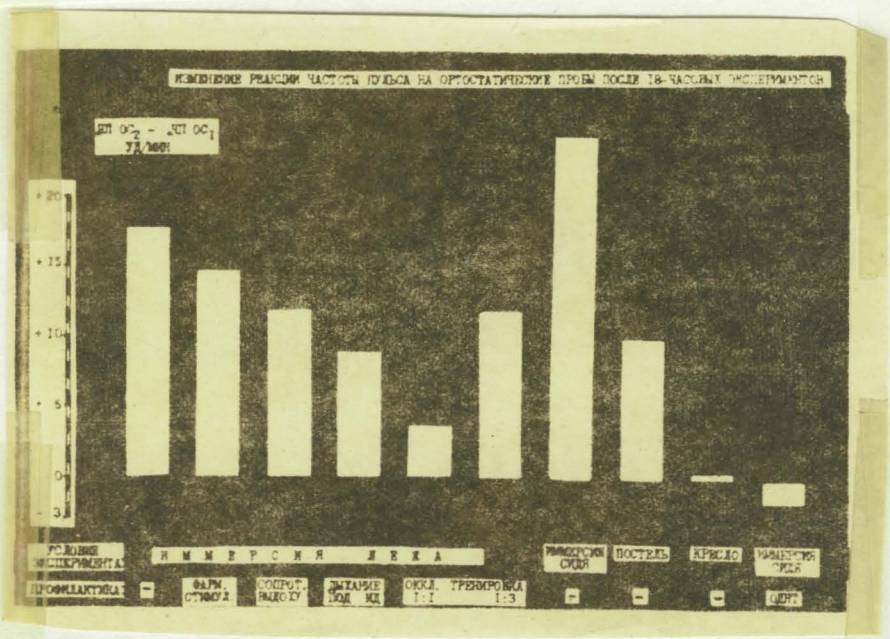


Figure 6



/Pulse freq. OC_2/-
/Pulse freq. OC_1/
— beats/min/——

/Condition of experiment/ /Immersion - laying down/ /Immersion seated/ /Bed/ /Chair/ /Immersion seated/

/Prevention:/ /-/ /Pharmac. stimulant/ /Resistance to expira./ /Breathing under press/ /Occlusion training/ 1:1 1:3 /-/ /-/ /-/ /NPLHB/

Figure 8. Changes in the Reaction of thePulse Frequency to Orthostatic Tests after 18-hour Experiments.

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For the purpose of analysis, 18-hour experiments were also performed with the subject in bed and in chairs. No less than 7 experiments were performed in each of these series, and the entire project included 85 experiments on 30 subjects. (Figure 8).

The height of the columns on the graph shows the difference in increase in pulse frequency following the experiment in comparison to the background examination.

The greatest changes in the reaction of the pulse rate to the orthostatic tests were observed in the control immersion series. Immersion in a sitting position caused a slightly greater change in the orthostatic resistance in comparison with immersion in a lying position, since the difference

the difference between the external pressure on the body and the pressure in the lungs was greater when the rib cage was submerged more deeply. In the control series, we frequently recorded instances of development of orthostatic collapse. The use of pharmacological stimulants failed to produce significant changes in the reaction as far as the pulse rate was concerned, but did re-

Figure 6

Systolic volume/stress index of myocardium
(arbitrary units)

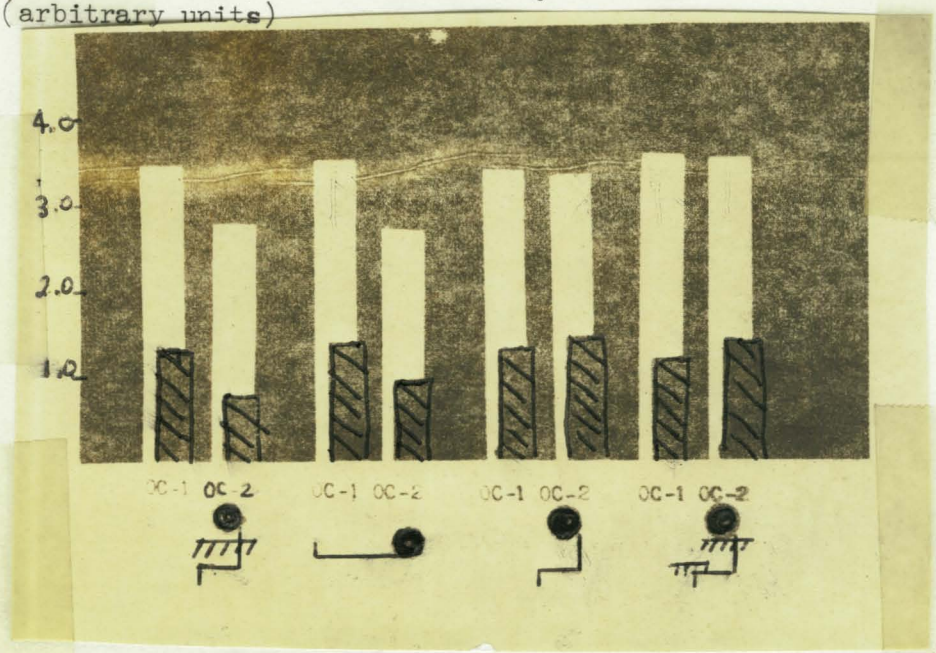

Figure 9
Sketches at bottom represent the position of the subjects;
Subject at extreme right and left were immersed in water.

liably prevent the development of collaptoid reactions. Respiration with a resistance on the exhaust was found to be insufficiently effective and had a tiring effect. Breathing under excess pressure produced slightly better results, but was quite fatiguing when a mask alone was used.

It was established that the effect of using occlusion thigh sleeves was very closely related to the use of a method of occlusion training. With one--minute pauses, this effect was quite clearly pronounced, but with 3-minute pauses it became insufficient and cases of development of orthostatic collapse could not be prevented.

Constant maintenance of the subjects in the immersion medium with reduced pressure on the lower half of the body to 25 mm Hg even increased the ability to withstand the orthostatic test relative to the original results. The changes in the water exchange and body weight were minimum in this series.

The data obtained in an analytical series involving 18-hour stays of subjects in a chair were most similar to these results; the effect of the hydrostatic pressure of the blood was retained and there were actually no changes in the orthostatic resistance. With bedrest and particularly control immersion, orthostatic disturbances were quite pronounced in these same subjects. (Figure 9)

The same characteristics were found in an analysis of the factors which in our opinion are most informative and consists in the quotient resulting from the division of the systolic volume into the stress index of the myocardium. The empty columns indicate the magnitude of the parameter prior to the test, while the colored sections represent the time of the test (on the left, before, on the right--after the experiment). It is obvious that control immersion and bedrest lead to more pronounced reduction of the parameter and consequently lead to deterioration of orthostatic stability, while staying in a chair and the effect of reduced pressure on the lower half of the body during immersion do not change or even improve it.

We can also see that in those cases when the magnitude of this parameter was less than 3 even prior to the orthostatic test, the severity of the orthostatic disturbances was particularly great. We feel that this parameter can be used for prediction to a certain degree.

The results of the last four series of brief experiments illustrate the significance of the hydrostatic factor in the genesis of the orthostatic instability and determine the relatively most effective way of preventing this problem by means of the use of negative pressure on the lower half of the body.

The use of a G-suit following immersion experiments promoted a significant improvement and return to normal of orthostatic reactions. Of all of the tested pressure arrangements in the G-suit chambers, the values in the range from 35 to 50 mm Hg were most preferable.

The reactions associated with the decrease in the motor activity cannot be made to show up sufficiently under the conditions of brief experiments simulating weightlessness. (Figure 10)

Therefore, in order to test methods aimed at the prevention both of the consequences of reduced hydrostatic blood pressure and hypodynamia, the most adequate model is a prolonged stay of the subjects in bed. In five series of 70-day and two series of 100-day experiments (22 subjects), we evaluated the possibility of preventing hypodynamic syndrome by using a group of pharmacological stimulants (caffein, securinine, phenamine in tablets), methods of physical training and occlusion thigh sleeves.

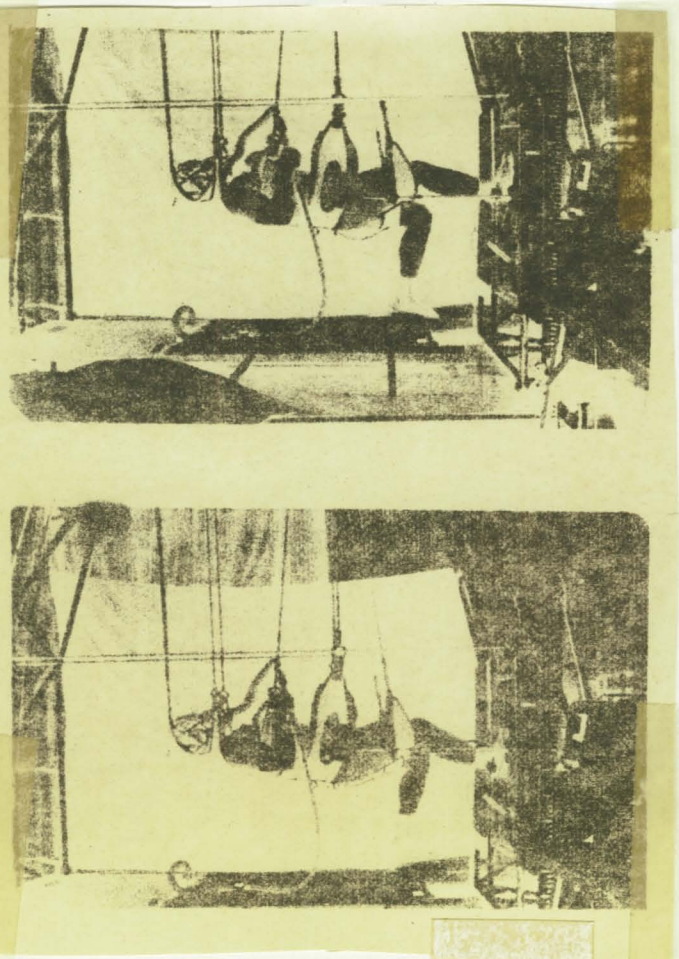

Figure 10.

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Figure 10.

Photographic Data

Photographic data illustrate the change in coordination of movement when walking in subjects in the control series immediately following the end of the 100-day experiment. There is a significant deterioration in regulation of the vertical posture, functions of equilibrium, nature of the gait. The subjects were practically unable to walk on their own; pains in the lower extremities were very characteristic of this period. The changes which were noted also involved the vegetative functions. This takes the form of rapid fatigue, considerable decrease in physical working ability, deterioration of the ability to withstand orthostatic tests. Even in those cases when the orthostatic tests did not end in collapse after the experiment, the increased stress on the cardiovascular system took a pronounced form.

For physical training in the horizontal position, the following were used: expanders, a bicycle ergometer and a complicated trainer which was developed by us in conjunction with V. I. Stepantsov, A. V. Yeremin and A. D. Antsipovich. It consisted of a vertically mounted sliding track with an electrical connection. The subject who was on a special suspension system and dressed in a G-suit was /8 fastened to the track by means of rubber shock absorbers with a force of 50 kg. Thus, a constant static load was imposed in the direction of the longitudinal axis of the body. The trainer made it possible to carry out exercises resembling walking, running, sitting down, jumping, lifting weights, etc.

The representatives of the trained group performed walking completely successfully, maintained their equilibrium well and did not require assistance.

Changes in the neuromuscular system, physical working ability, bone tissue, metabolic processes and vegetative functions were all less in this group.

We detected relatively fewer changes in comparison to the controls in regard to the orthostatic stability as well. (Figure 11)

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Figure 11.

In two series of 70-day experiments, physical exercises were supplemented periodically (9 hours a day) by the use of occlusion thigh sleeves (pressure = 70 mm Hg for 1 minute, with 1 minute pauses).

It was found, however, that the changes in the pulse frequency, systolic blood volume and pulse pressure in the orthostatic tests in these two series increased in comparison to the results which were obtained with a single physical trainer.

The probable cause of the relative deterioration of orthostatic stability when using occlusion sleeves may have to do with the fact that their use retains a high level of distension of the vessels in the lower extremities, while in the series without the use of these sleeves there was a regular decrease in the distension of the vessels. Hence, the side effects which were physiologically undesirable and were caused by occlusion training evidently prevailed over those effects for which they were designed. /9

The use of pharmacological stimulants in the course of hypodynamia and one hour prior to the orthostatic test did not reduce the severity of the physiological changes in comparison to the data from the control series, but excluded cases of development of orthostatic collapse which were observed in the subjects in the control group. (Figures 12 and 13)

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Figure 12.

Figure 13.

In four series of 30-day experiments in which 12 subjects stayed in bed, methods of affecting the negative pressure in the lower half of the body were tested (NPLHB). One of the devices used was a cylindrical space made out of cloth through which air would not pass, and another resembled a chair with a

fixed vacuum capacity for the lower half of the body. In one series, we tested the effect of the NPLHB for 6 hours a day every day at a level of 30 mm Hg. However, this arrangement proved to be difficult to withstand, caused fatigue and did not produce positive results.

In the second series, the NPLHB system was used only during the last five days spent in bed and provision was made for a gradual increase in the level of action from 15 to 30 mm Hg, as well as a period of training with a system that could be freely selected, during which levels of discharge on the order of 60 mm Hg were achieved. The time of daily exposure to NPLHB was therefore between 2.5 and 3 hours. (Figure 14)*

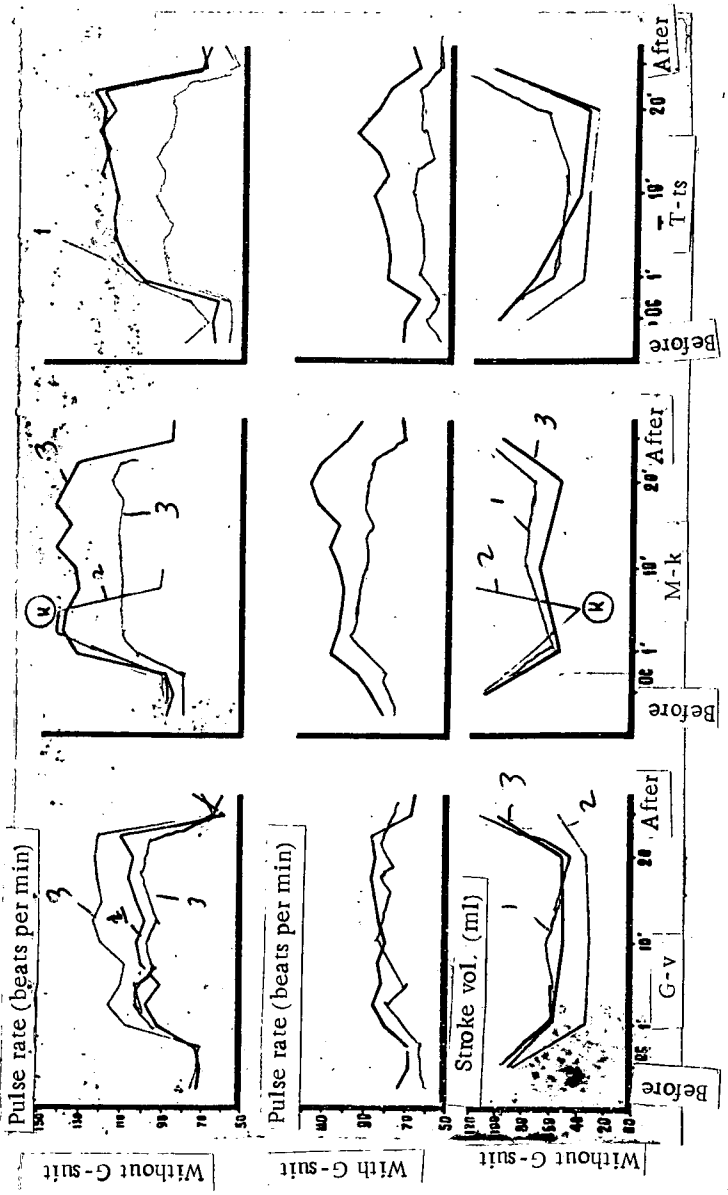

Figure 15. Pulse Rate and Stroke Volume in Orthostatic Tests (30-Day Experiment).

The volume of circulating plasma (VCP) in the subjects of this series decreased significantly during hypodynamia (data of A. Savidova). However, 3 days after the beginning of the training exercises with NPLHB, two of the subjects showed a tendency toward restoration of the VCP. A third subject did not show this effect. /10

It should be pointed out that the subject withstood the training effects of the NPLHB worse and was trained in a slightly smaller volume than the other representatives of this group.

The recovery period following the end of the experiment was slower for him than for the other subjects (more than a

*Translator's Note: Figure 14 was not available.

month), since not only the NPLHB but the actual gravitational effect was not always able to return the physiological changes to normal which had been caused by hypodynamia. (Figure 15).

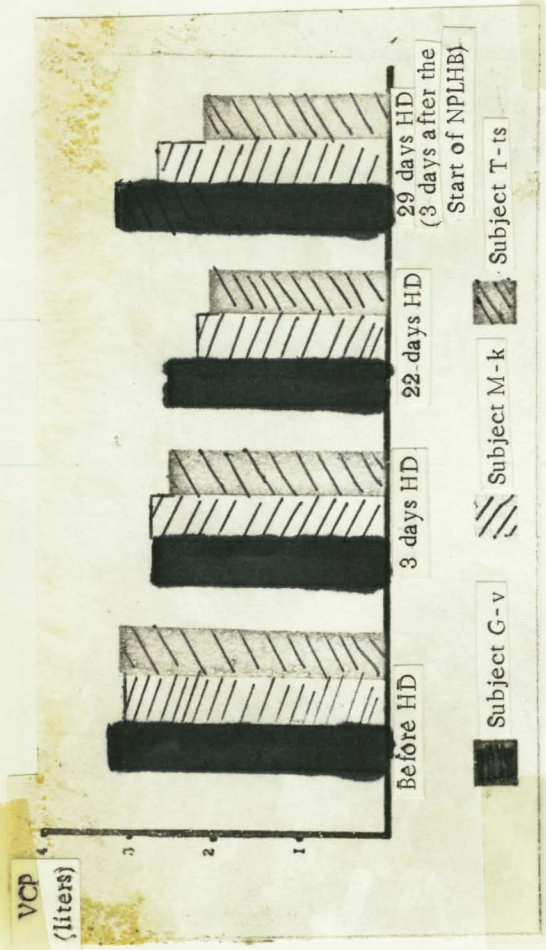

Figure 14

In comparing the results of the orthostatic tests that were performed before the experiment (blue line) for 25 days of hypodynamia, i.e., prior to the beginning of the NPLHB program (green line) and after the end of the experiment (red line), we could see that the negative pressure normalized the orthostatic stability in one subject, prevented development of collapse in a second and had very little influence on the state of the orthostatic stability in a third subject. It was in this latter subject that NPLHB had no effect on the VCP. (Figure 16).

The complex application of daily physical training in the trainer described above with application of NPLHB during the last five days of hypodynamia was studied in the following series of experiments. In comparison to the data of the control series, the state of orthostatic stability in the trained group on a 25-day experiment varied to a relatively slight degree.

A 5-day cycle (with 26 to 30 days) for using the NPLHB showed additional normalizing effects on the orthostatic reactions. (Figure 17). /11

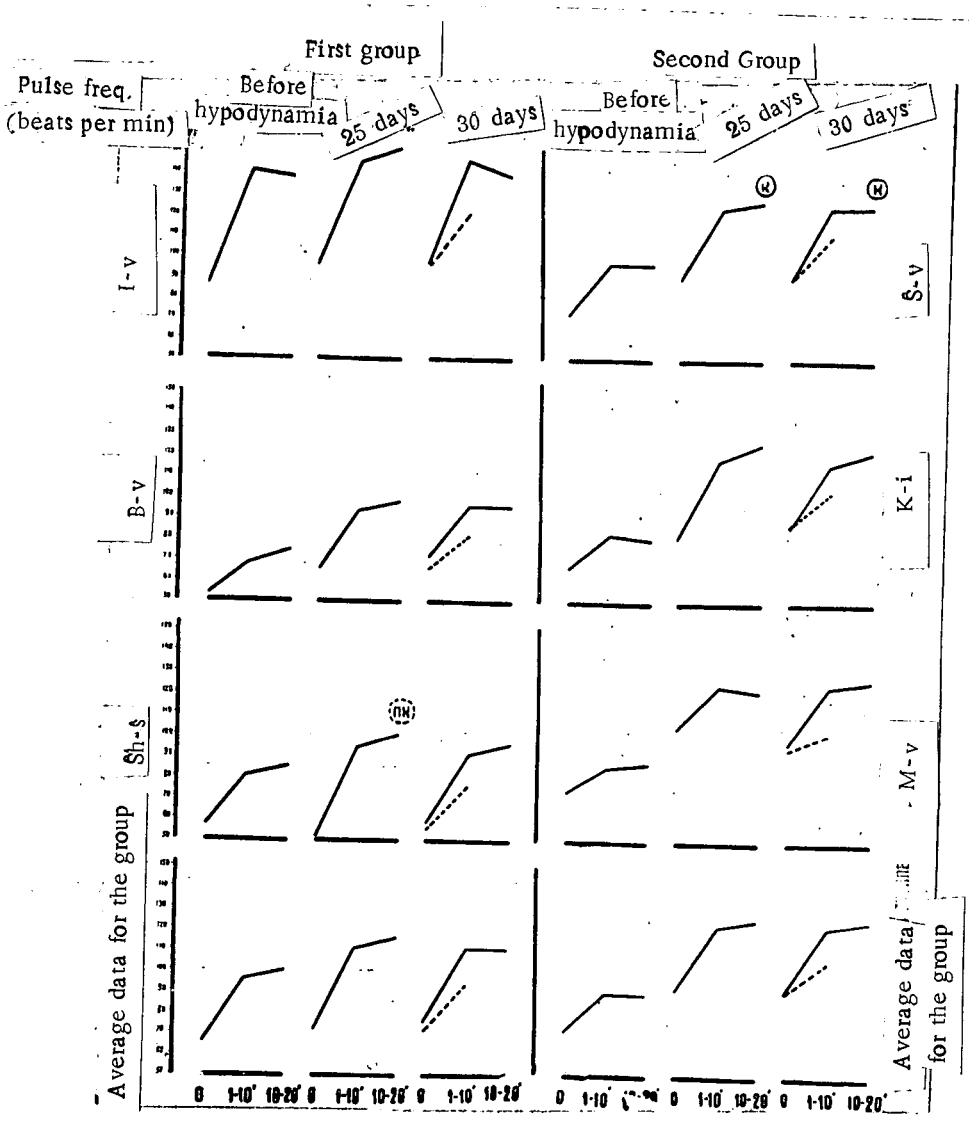

Figure 16. Change in Pulse Frequency in Orthostatic Tests.

The most promising method of preventing orthostatic difficulties in laboratory simulations of weightlessness is the use of a group of preventive measures which include in particular a G-suit. Theoretically, its use in all series would reduce the severity of the orthostatic reactions, but in the control series and in the series with daily fatiguing effects of the NPLHB it did not cause complete normalization of the reactions as far as the pulse frequency and other hemodynamic factors in the vertical position were concerned. The white lines show the level of the pulse rate in the orthostatic samples prior to the beginning of the experiment. On the other hand, in the two series where the use of the NPLHB was effective, the use of the G-suit was able not only to normalize the orthostatic reactions but also to reduce them relative to the results of the background orthostatic test.

In comparing the results obtained by experimental studies, it is necessary to note that the use of all the tested preventive measures did not completely prevent development of unfavorable consequences of prolonged clinostatic hypodynamia, but unquestionably made their development less severe. This was expressed in the form of significantly reduced disturbances of motion coordination, vegetative reactions to the orthostatic tests and physical stress. Changes involving metabolic processes, muscular atrophy, decalcification of bone, etc. were also less pronounced. It should be mentioned that certain preventive measures (occlusion sleeves) which showed a high level of effectiveness in an 18-hour experiment involving immersion in water turned out to be ineffective in long experiments with clinostatic hypodynamia. /12

Decompression of the lower part of the body in brief experiments produced a more positive effect than in long experiments. This may obviously be explained by the different pathogenetic mechanism in the development of orthostatic instability in brief and long experiments. We cannot exclude the pos possibility that in the long experiments the factor of reduced hydrostatic blood pressure plays a lesser role in comparison to hypodynamia than in brief immersion tests. It is very likely that the selected methods of occlusion and decompression training were not the best ones.

Nevertheless, a positive preventive effect produced by the group of methods and means which includes training on a physical trainer, training in a vacuum chamber, use of secophene before the end of the experiment and a G-suit when changing to the vertical position was sufficient so that we can recommend its use on the 24-day flight of the "Salyut" craft. It is not possible to evaluate the effectiveness of the methods used in flight at the present time. Nevertheless, it is encouraging to hear the positive subjective opinion of the cosmonauts regarding these preventive measures: vacuum chambers, physical training and stressed suits. It should be pointed out that the crew of the "Salyut" spacecraft used these measures, and sometimes (on their own initiative) exceeded the intensity of the desired effect.

Thus, the influence of negative pressure on the lower half of the body in /13
a state of weightlessness, in the opinion of the cosmonauts, was easier to withstand and created much more pleasant sensations than under terrestrial conditions, when it was performed in a horizontal position.

The level of the stress was occasionally raised to 70 mm Hg. In addition, we can state that physiological changes in response to the functional test involving the use of the NPLHB (27 mm Hg--2 minutes; 36 mm Hg--3 minutes) in a state of weightlessness, as we would expect, increased relative to the data from the preflight observations. (Figure 18)

Both the original value and the increases in the pulse rate during flight (red color) turned out to be higher than in the three examinations before the flight (yellow color). It is true that the commander of the crew showed a slight excess in the NPLHB mode during the test in-flight. Evidently certain differences in the subjective and objective evaluations of the ability to withstand NPLHB had to do with the specific nature of the emotional state of the crew members and the fact that this effect created a sensation of returning to terrestrial conditions.

In conclusion, we can say that although a final solution of the problem of preventing unfavorable influences of prolonged weightlessness on the human organism is still far from available at the present time, there is a real

basis for taking the first practical steps and achieving further progress in this area of space medicine.

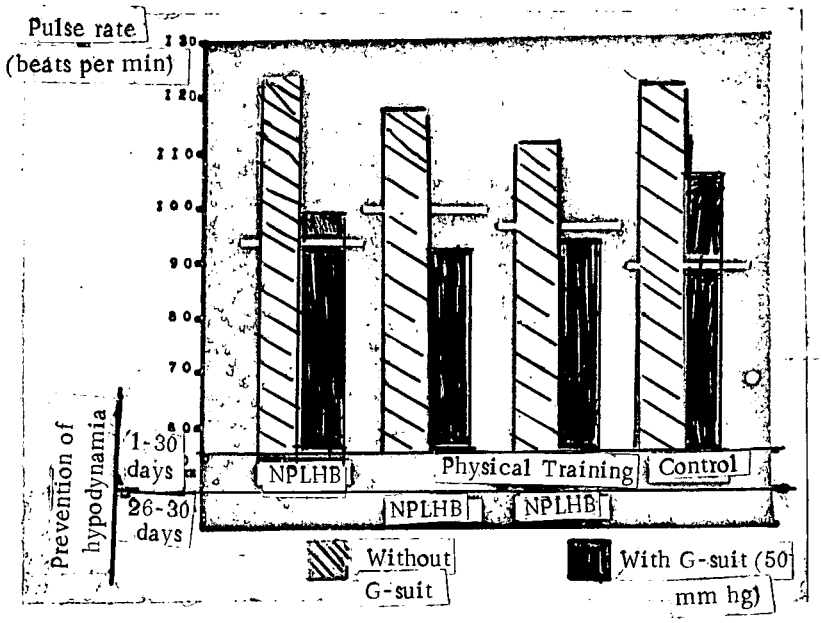

Figure 17. Pulse Frequency in Orthostatic Test Following 30 Days of Hypodynamia.

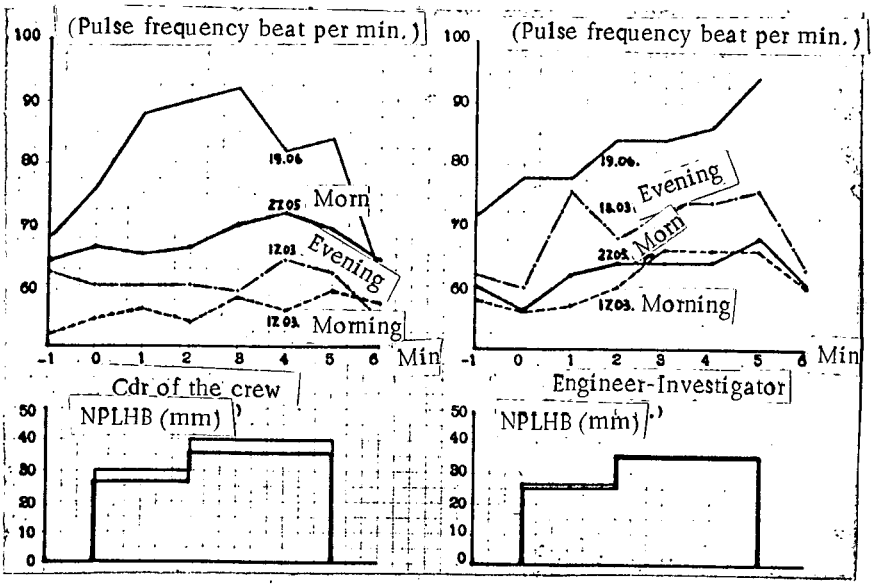

Figure 18. Change in Pulse Frequency in the Commander of the Crew and the Engineer-Investigator During a Functional Test with NPLHB Prior to the Beginning and After 18 Hours of the Flight.